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Human Capital Formation under Product Market Uncertainty

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Abstract

We study an imperfectly competitive local labour market with heterogeneous firms and workers when product demand is uncertain. In particular, we model how the interaction of price shocks and labour market structure affects workers' investment into general versus specific human capital. Our results suggest that, in a pooled labour market, symmetric shocks depress the overall level of human capital formation. As closer European integration will affect the pattern of regional specialisation, our findings may have implications for a region's long-run growth prospects as well as its capacity to adapt to structural change.

JEL classification: I20, J24, J41

Keywords: human capital, heterogeneity, unemployment, labour market pooling

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1 Introduction

Among the important and highly controversial issues discussed concerning European integration are the type and frequency of product market shocks and their consequences for cross-regional economic performance. If closer integration generates a pattern where similar industries become spatially more concentrated industry-specific shocks will turn into regional shocks with possibly detrimental effects on a region's wages and employment. In contrast, under a diversified industrial structure, firm-specific shocks may lead to a labour market pooling advantage. We argue that such shocks will not only trigger a response by firms which will adjust wages and employment but will, in the long term, also modify a worker's decision on the amount of investment into human capital. This, in turn, will influence a worker's employability as well as productivity. The process of human capital formation might thus modify the impact of shocks on a region's unemployment and wage level. Human capital decisions, in the aggregate, then determine the capability of a regional workforce to adapt to structural change. In addition, given the importance that models of endogenous growth attach to human capital investment as the engine of growth, there may be impacts on a region's growth rate.

The paper presents a microeconomic model of human capital formation in an imperfectly competitive local labour market, with heterogeneous workers and firms, when product markets are characterised by price uncertainty. We analyse a setting where firms are hit by demand shocks determining either a good or a bad state. Firms produce for a competitive output market and with differing technologies, thus requiring diverse skills. In anticipation of firm behaviour, workers choose between specialising into a certain type of skills, and accumulating general skills. We thus look at the endogenous determination of the level of both horizontally differentiated and general human capital.

Our findings suggest that, with equal probability on each shock scenario,

a higher output price, meant to represent a booming industry, or an industry favoured by structural change, will raise the return to both general and specific human capital. Labour market size, which could alternatively be interpreted as the degree of skill specialisation or diversification, however, has a differential impact. As the market is enlarged, workers are likely to form more general human capital at the expense of specific human capital. In a larger market, where the number of workers rises while the number of firms remains constant, there is an advantage to being more flexible, i.e. offering more general human capital as this increases a worker's suitability for other firms. Modifying the shock probability structure, we find that under more symmetric shocks the incentive to invest in either kind of human capital is weaker. Interpreting the symmetry of shocks as an indicator of the degree of regional industrial specialisation, we infer that, everything else being constant, specialised regions will be less flexible in their response to structural change and also less productive. Bearing in mind the importance of human capital for economic growth, adverse effects on the growth rate of specialised regions may follow.

Based on the Hotelling model of product differentiation (HOTELLING 1929), workers locate along a line with their addresses reflecting their skill types. Two firms locate each at the end of the line, with their position indicating their skill requirements. We thus capture the idea of two-sided heterogeneity in the labour market. Wages are determined by strategic considerations of the two firms as they compete for workers. Another important aspect of the model is that we allow for unemployment which arises as the combined consequences of a price-induced fall in labour demand and mismatch.

On the basis of their expectations of shock realisations, workers will choose those levels of the two types of human capital that maximise their expected utility, a function of expected income minus the cost of skill acquisition. We then look at the effects of changes in exogenous variables, in particular the shock specification, but also labour market size and output price, on the optimal levels of general and

specific skills[1]. We thus highlight the mechanisms by which the conditions on product markets, such as uncertainty, are transmitted to labour markets where they influence the trade-off in skill acquisition. Cross-regional asymmetries in any of the exogenous variables determining workers' optimisation problem will then cause regional variation in this trade-off as well as in the overall level of human capital formation. This in turn will give rise to differences in (short-run) reactions to shocks, and in long-run growth prospects.

Our paper builds upon the idea that human capital has both a general and a specific component, as expressed in KIM (1989)[2]. In a series of papers, KIM (1989; 1990; 1991) studies the impact of local labour market size on wages and human capital formation. Adapting the SALOP (1979) model of product differentiation to the labour market, the skill space is represented by the circumference of a circle. KIM (1989) finds that as the density of workers rises new firms enter the market. It follows that, firstly, wages rise due to better matching, and secondly, workers invest more in intensive and less in general human capital.

The endogenous formation of human capital in a heterogeneous labour market is also analysed by THISSE, ZENOU (1995), and HAMILTON *et al.* (2000). In both cases, firms compete for workers and set Bertrand wages. Product markets are, however, absent. THISSE, ZENOU (1995) then look into the question of how the equilibrium varies with the allocation of the associated training cost, but also with changes in market size. HAMILTON *et al.* (2000) derive the labour market outcome under different information structures.

Our approach is closely related to JELLAL *et al.* (1999) who investigate the effects of product market fluctuations on the labour market. Both firms and

[1]Note that specific human capital here is somewhat different from specific human capital in the spirit of BECKER (1964). The latter refers to firm-specific human capital while we refer to skill specialisation. In our definition, specific human capital can be employed by other firms, though less productively, if they produce with a similar technology, and workers acquire it before entering the labour market.

[2]Kim refers to specific human capital as intensive.

workers are heterogeneous. Full employment and unemployment equilibria are derived, with unemployment being the result of volatile prices and of mismatch. However, our paper differs in two important aspects. Firstly, human capital in our model is endogenous. Secondly, in our set-up price shocks are revealed and firms adjust wages and employment, while workers form expectations of their wage. In JELLAL *et al.* (1999), the wage is not random because actual shocks are never revealed. Price uncertainty is represented by the variance of a distribution with constant mean. As such it enters the utility function of risk-averse firms. Firms then transfer the risk on workers by offering lower wages.

Other studies have also recognised the importance of local labour market heterogeneity, and have applied the theme to various contexts. For example, RITTER, WALZ (1998) combine the matching framework with efficiency wages and are thus able to generate equilibrium unemployment. HELSLEY, STRANGE (1990) incorporate labour market heterogeneity into a general equilibrium model of a system of cities. With cities' population growth being determined endogenously over migration, the labour market can be shown to generate agglomeration economies as both workers and firms expect to be better matched in larger cities.

Our paper adds to the existing literature in that it synthesises two so far separately treated issues: the endogenous formation of human capital, and the link between product and labour markets. It also delivers an explanation of unemployment which is allowed to have further impacts on worker behaviour. The important elements of this paper are the specification of product market shocks, its interaction with the labour market setting, and the subsequent modification of a worker's human capital investment decision.

We will proceed as follows: in the next section, we introduce the model. Section 3 presents the derivation of labour market equilibria for given levels of human capital. We then look at the optimal investments into human capital in section 4. Before concluding, we discuss, in section 5, our model within the context of European integration and the industrial structure of regions.

2 The Model

2.1 The Labour Market

2.1.1 Workers

Workers form human capital and subsequently offer skilled labour to firms. As a distinctive characteristic of our labour market modelling, human capital is assumed to be two-dimensional. A worker can invest in specific human capital, b, and in general human capital, K. While b increases the productivity with a given firm, K counters the productivity loss resulting from mismatch. We also allow workers to be horizontally differentiated in terms of their individual skills. These skills are completely worker innate and may not be influenced.

As an illustration of specific human capital, b, we may think of a technician who works with a firm producing refrigerators but could also move to a firm producing washing machines as the heating and cooling technologies require similar knowledge. The two firms belong to different industries, however, with both goods being consumer durables the two industries are not too differentiated with respect to demand conditions.[3] In case a worker is employed by a firm with less than perfectly matching skill requirements, general human capital, K, will help the worker to adapt to the new requirements. Such general human capital could comprise, for instance, computing, or general mathematical, or communication skills.

Our modelling approach corresponds to the familiar Hotelling model of product differentiation: Worker skills will be distributed and indexed along a line, with

[3] Kim (1989) uses the example of a cook and an architect who, if forced to swap jobs, would become unproductive. So, Kim looks at a model of a rather high degree of skill differentiation where some workers may not be productive in other workers' jobs. By contrast, we look at a labour market segment where the two firms are in direct competition for all the workers. It means that, in the absence of shocks, all workers would have positive productivity with both firms.

$x \in [0; L]$ determining a worker's skill type, and b the level of any particular type x. Thus $[0; L]$ denotes the set of all existing types of skills.

When choosing their type of human capital in stage 1, workers do not know which address they will have. Their choice variables are the level of both kinds of human capital. In stage 2, it is nature that assigns worker skills, x, distributes workers continuously and equally along $[0; L]$, and thus reveals their type. Each worker's type of specific human capital given by their address on L. Finally, human capital investments are costly, the cost function, $C(b, K)$, being convex:

$$C_b(b, K) > 0; C_K(b, K) > 0$$
$$C_{bb}(b, K) > 0; C_{KK}(b, K) > 0; C_{bK}(b, K) = 0 \tag{1}$$

2.1.2 Firms and Technology

Firms are also heterogeneous in terms of their technology. The only input to production is skilled labour but the type of skill that firms demand differs. There are two firms in the local labour market. We impose the assumption that the two firms reside each at the end of line L. Analogously to workers, a firm's position indicates its skill requirement. A firm-worker pair is perfectly matched when their addresses on L coincide. The further the firm and worker are apart, the higher the degree of mismatch. Workers then have to be trained in order to match the firm's requirement. Training, however, is costly, and the question arises who will pay for these costs, the firm or the worker. Here, we follow HAMILTON *et al.* (2000) and impose the training cost upon workers as this induces efficient matching. It generates an incentive for workers to choose the firm offering the highest wage net of training cost.

Workers need to incur training costs if their specific skill does not precisely match the firm's skill requirement. The training costs, g, will increase with skill distance x but decrease with general knowledge K:

$$g = \frac{x}{K} \tag{2}$$

2.2 The Product Market

Product markets are characterised by price uncertainty. There exists an exogenously given price level p subject to shocks. We limit the price shock to be of magnitude A, and distinguish 3 cases: a positive price shock hits both firms with probability π_1; with probability π_2 both firms are hit by a negative shock, and with probability $1 - \pi_1 - \pi_2$ the two firms are asymmetrically hit. This is summarised in Table 1[4]. We will later modify the shock structure such that there

		Firm 2	
		$p + A$	$p - A$
Firm 1	$p + A$	π_1	$\frac{1-\pi_1-\pi_2}{2}$
	$p - A$	$\frac{1-\pi_1-\pi_2}{2}$	π_2

Table 1: Probability of shock/price realisations

is a distinction only between asymmetric and symmetric shocks. The output price is thus composed of a constant component p and a stochastic component $A \in \{-A, +A\}$.

Having introduced the product market, we are now able to illustrate the structure of our set-up in Figure 1 for the case of positively symmetric shocks as an example. Here, the vertical axis represents worker productivity measured in units of marginal product.

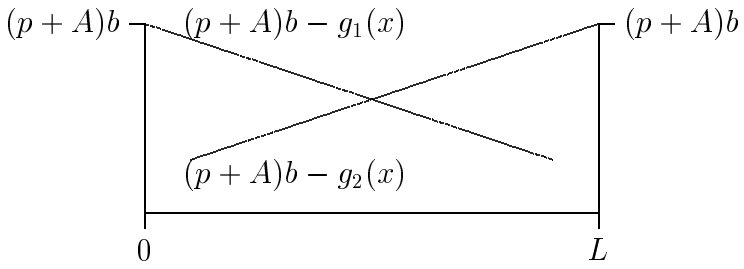

Figure 1: Heterogeneity, training cost, and price realisation

[4]See Appendix A.6 for a characterisation of the underlying distributions.

2.3 Wages

We assume an informational asymmetry: after nature's draw, workers learn about their type of skill (i.e. their position on L), firms do not. They only know the common level of b and K (which will be the same for all workers for reasons of symmetry). This informational asymmetry commands that firms set wages. By burdening workers with the training cost, firms are able to induce efficient matching, i.e. workers choose the nearest firm. Finally, since with training all workers are equally productive with a given firm, the firm sets a single wage.

When price shocks occur, firms adjust via wages. Workers then compare wages with their training costs and accept a job offer only at a non-negative net wage. When training costs exceed the paid wage, some workers may choose not to enter an employment contract but rather stay unemployed. Workers also anticipate firms' reactions to shocks and know the shock probabilities. Consequently, workers are able to form expectations of their average expected net wage and will choose those levels of b and K which maximise their income. The expected net wage is then the sum of the net wage obtained in the individual shock scenarios, weighted by their probabilities, less the cost of the human capital investment. The net wage in each scenario, in turn, is the wage paid by the firm less the expected training cost, times the employment rate.

2.4 Sequence of Events

The game consists of the following stages, in chronological order:

Stage 1: Workers choose their investment into specific b and general human capital K.

Stage 2: Nature decides upon worker types and price shocks.

Stage 3: Firms set wages such that profits are maximised. This implicitly determines employment.

The model is solved by backward induction.

3 Labour Market Equilibrium

We now work through three cases distinguished by the realisation of shocks. First, we derive equilibrium levels of wages, ω_{ij}, expected wages, ω_i^e, and of employment, $\bar{x}_i$.[5] The general procedure is, for a given realisation of shocks, to let firms set wages such that profits are maximised. Then workers determine their expected wage. This corresponds to stage 3. At stage 2, shocks materialise. Next, in section 1, workers decide on the optimal investments into general and specific knowledge, K and b (stage 1). Finally, we look at comparative static results, to see how changes in exogenous parameters will affect the equilibrium values of b and K.

3.1 The case of positive shocks for both firms

Both firms experience the same positive price shock, $+A$, which raises workers' productivity (in money terms) to $b(p + A)$. Subsequently, firms' labour demand shifts upwards. Each firm would like to employ all workers in the market, and all workers wish to be employed as they would receive a positive net wage at either of the two firms. Firms now have to compete for workers a la Bertrand. Employment levels at both firms will then be determined by a marginal worker condition: there exists a marginal worker at point $\bar{x}_1$ on line L who is indifferent between working for either of the two firms. This marginal worker splits L into two sub-segments, with those workers employed at firm 1 to the left, and workers employed at firm 2 to the right. For this worker, it must be that the wage net of training cost at firm 1 and firm 2 is the same.

$$\omega_{11} - \frac{\bar{x}_1}{K} = \omega_{12} - \frac{L - \bar{x}_1}{K}$$

[5] The first variable denotes the wage offered by firm j in case i while the latter is the expected wage net of training cost in case i.

Solving for $\bar{x}_1$:

$$\bar{x}_1 = (\omega_{11} - \omega_{12})\frac{K}{2} + \frac{L}{2} \tag{3}$$

Firm 1's profits can be calculated as the integral over the marginal value product of workers less the wage, the limits being given by employment. In general:

$$P_{11} = \int_0^{x_1} (b(p - A) - \omega_{ij})\, dx \tag{4}$$

Because of the equality of productivity and of wages at both firms, this expression can be simplified to

$$P_{11} = (b(p + A) - w_{11})\bar{x}_1 \tag{5}$$

i.e. profits are equal to the the difference between a worker's marginal value product and their wage, times employment.

Plugging (3) into (5) , profit maximization with respect to the wage yields:

$$\frac{\partial P_{11}}{\partial \omega_{11}} = (p + A)b\frac{K}{2} - 2\omega_{11}\frac{K}{2} + \omega_{12}\frac{K}{2} - \frac{L}{2} = 0. \tag{6}$$

By symmetry, the same procedure and results apply to firm 2's optimisation problem, so that wages paid at both firms are the same

$$\omega_{12} = \omega_{11}. \tag{7}$$

Therefore, it must be that

$$\bar{x}_1^* = \frac{L}{2} \tag{8}$$

i.e., workers are equally split between both firms. Combining (7) and (8), we obtain

$$\omega_{12}^* = \omega_{11}^* = b(p + A) - \frac{L}{K} \tag{9}$$

We further have to ensure that even the worker with the worst match, that is at $\bar{x}_1$, receives a non-negative net wage. This results in the following condition (participation constraint):

$$b(p+A) - \frac{3L}{2K} \geq 0 \tag{10}$$

Workers anticipate firms' wage and employment decisions, and subsequently form expectations over their net wage (paid wage net of training cost) which we will call the expected wage ω_1^e. Since there is full employment, and both firms pay the same constant wage to all workers, the only uncertainty results from a worker's type, i.e. her ex ante unknown position on L. Her type will influence her training cost and is revealed by nature after human capital investments have been completed.

The expected training costs for workers employed at firms 1 and 2 are given by

$$g_1 = \frac{E_{11}}{K} \quad \text{and} \quad g_2 = \frac{L - E_{12}}{K} \quad , \tag{11}$$

where

$$\begin{aligned} E_{11} &= \frac{\bar{x}_1}{2} = \frac{1}{4}L \\ E_{12} &= \frac{L - \bar{x}_1}{2} + \bar{x}_1 = \frac{3}{4}L \end{aligned}$$

reflect the average distance of a worker from firm 1 and firm 2.

Actual training cost are increasing in worker type, i.e. in her distance to the firm. They are decreasing in the level of general human capital K, reflecting the idea that it is easier for a worker with more general skills to adapt to the specific requirements of either firm.

The expected wage in case 1 can then finally be written as

$$\begin{aligned} \omega_1^e &= (\omega_{11}^* - \frac{E_{11}}{K})\frac{1}{2} + (\omega_{12}^* - \frac{L - E_{12}}{K})\frac{1}{2} \\ &= b(p+A) - \frac{5}{4}\frac{L}{K} \end{aligned} \tag{12}$$

i.e. the sum of the wage paid at each firm weighted by the probability to be employed at the respective firm. What we find in this case is that firms pay a wage below a worker's productivity. The wage is determined as productivity less the training cost of the least productive worker the firm could obtain in the market: the worker at the other end of the skill spectrum. This result follows from the oligopsonistic wage-setting, and is illustrated in Figure 2.

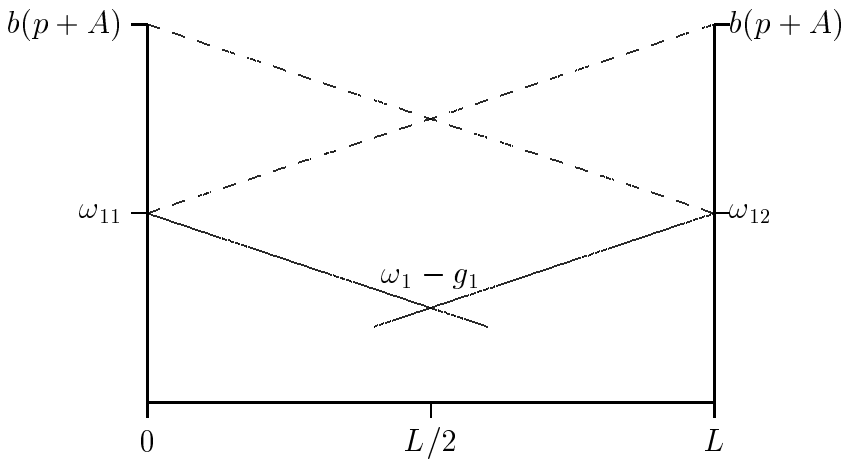

Figure 2: Labour market equilibrium in case 1

3.2 The case of negative shocks for both firms

By definition, this case will be characterised by unemployment. Shocks are sufficiently negative to depress wages at both firms to the extent that some workers in the middle of L, those with the highest degree of mismatch, would have to work at negative net wages. We now need two marginal-worker conditions:

$$\begin{aligned} \omega_{21} - g_{21} = \quad & \omega_{21} - \tfrac{\bar{x}_{21}}{K} \quad = 0 \\ \omega_{22} - g_{22} = \quad & \omega_{22} - \tfrac{L-\bar{x}_{22}}{K} \quad = 0 \end{aligned}$$

Because of symmetry, we restrict our attention to firm 1.

Firm 1's profits can again be written as

$$P_{21} = (b(p-A) - \omega_{21})\bar{x}_{21} \tag{13}$$

just that the determination of the marginal worker $\bar{x}_{21}$ is different now.

An important feature of the unemployment case is that we now encounter a monopsony game: workers are productive with at most one firm. Firms no longer compete for workers and can therefore set monopsony wages.

Profit maximisation with respect to the wage yields:

$$\frac{\partial P_{21}}{\partial \omega_{21}} = (p - A)bK - 2K\omega_{21} = 0$$

resulting in the monopsony wage which equals just one half of workers' productivity, and is independent of both market size L and general human capital K (a result of the different marginal worker condition).

$$\omega_{21}^{*} = \frac{b}{2}(p - A) \tag{14}$$

The following restriction is required to ensure the existence of unemployment:

$$b(p - A) - \frac{L}{K} \leq 0 \tag{15}$$

The expected wage in case 2 is then:

$$\omega_{2}^{e} = \frac{1}{4L}(p - A)^2 b^2 K \tag{16}$$

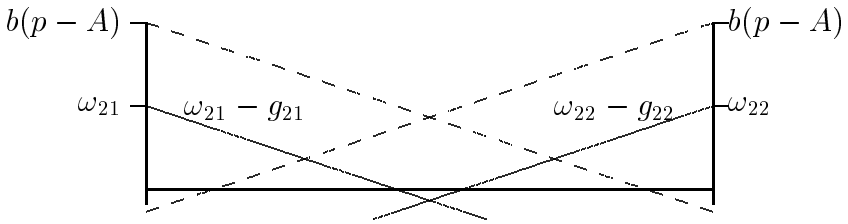

Figure 3: Labour market equilibrium in case 2

3.3 The case of a positive shock for firm 1, and a negative shock for firm 2

The derivation of the equilibrium wage and employment at each firm proceeds as before, the main difference being a negative price shock at firm 2. Firm 1 can afford to pay a higher wage so that its labour demand exceeds that of firm 2. As a consequence, the marginal worker is driven closer to firm 2, implying a larger share of employment for firm 1.

Firm 1's profits are:

$$P_{31} = (b(p + A) - w_{31})\bar{x}_3 \tag{17}$$

with the marginal worker residing at

$$\bar{x}_3 = (\omega_{31} - \omega_{32})\frac{K}{2} + \frac{L}{2}$$

Profit maximisation with respect to the wage then yields:

$$\frac{\partial P_{31}}{\partial \omega_{31}} = (p + A)b\frac{K}{2} - 2\omega_{31}\frac{K}{2} + \omega_{32}\frac{K}{2} - \frac{L}{2} = 0$$

so that the optimal wage for firm 1 satisfies

$$\omega_{31} = (p + A)\frac{b}{2} + \frac{1}{2}\omega_{32} - \frac{L}{2K}. \tag{18}$$

Similarly, we can derive the optimal wage for firm 2

$$\omega_{32} = \frac{b}{2}(p - A) + \frac{1}{2}\omega_{31} - \frac{L}{2K}. \tag{19}$$

Combining equations (19) and (18) then yields:

$$\begin{aligned} \omega^*_{31} &= bp + \frac{1}{3}Ab - \frac{L}{K} \\ \omega^*_{32} &= bp - \frac{1}{3}Ab - \frac{L}{K} \end{aligned} \tag{20}$$

As in the first case, we have to ensure that the marginal worker receives a non-negative net wage which requires:

$$pb - \frac{3L}{2K} \geq 0 \tag{21}$$

Expected training cost will be:

$$g_{31} = \frac{E_{31}}{K} \quad \text{and} \quad g_{32} = \frac{E_{32}}{K}$$

where

$$\begin{aligned} E_{31} &= \frac{\bar{x}_3}{2} \\ E_{32} &= \frac{L - \bar{x}_3}{2} + \bar{x}_3 \end{aligned}$$

Workers then derive the expected wage as:

$$\begin{aligned} \omega_3^e &= (\omega_{31}^* - \frac{E_{31}}{K})\frac{\bar{x}_3}{L} + (\omega_{32}^* - \frac{L - E_{32}}{K})\frac{L - \bar{x}_3}{L} \\ &= pb + \frac{1}{9L}b^2A^2K - \frac{5}{4}\frac{L}{K} \end{aligned} \tag{22}$$

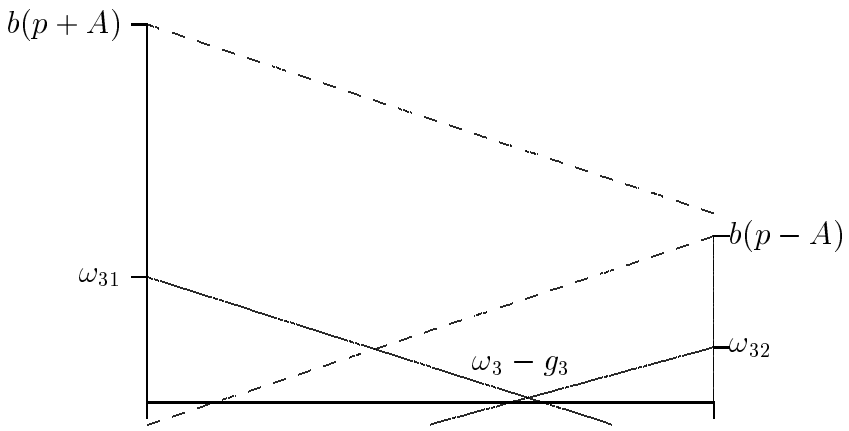

Figure 4: Labour market equilibrium in case 3

4 Endogenous human capital formation

We now turn to a worker's human capital decision, formally given as

$$\max_{b,K} \quad \pi_1\omega_1^e + \pi_2\omega_2^e + (1 - \pi_1 - \pi_2)\omega_3^e - C(b, K) \tag{23}$$

The worker maximises the difference between the expected net wage of all three cases and investment cost, where the weights reflect the probabilities of the respective cases occuring.

Using the first-order conditions for a maximum, and taking into account the parameter restrictions imposed in the previous section and by the second-order conditions, we can derive comparative statics effects.[6]

Result 1:

$$db^*/dp > 0; \quad dK^*/dp > 0$$

An increase in the expected (or average) price, p, raises the value of each unit of both, specific, b, and general human capital, K. This implies that in industries where workers generate a higher value product, incentives to improve and develop human capital are also higher.

In all three shock scenarios, a higher output price, interpreted as the firm belonging to a booming industry, directly translates into a higher wage offer by the two firms. Hence, a worker's optimal level of b, b^*, increases in all cases. In contrast, the investment into general human capital is only affected by the price p in the case of symmetrically negative shocks, with general human capital serving as a means to reduce the risk of unemployment. An increase in p, feeding through into higher wages, also raises the returns to avoiding unemployment. As both types of human capital are complements in this case, we find an unambiguously positive effect on their optimal levels. As a result, we would expect to find significantly higher wages in these industries due to both the (exogenously) higher productivity and the endogenously higher levels of human capital. Finally, unemployment would be lower in these industries, while turnover would be higher

[6]See the appendix for a full derivation and specification of the individual effects (A.2, A.4) as well as the derivation of the first- and second-order conditions (A.1, A.3).

if the firms were asymmetrically hit by productivity shocks.

Result 2:

$$db^*/dA; \;\; dK^*/dA$$

The overall impact of shock A on the equilibrium levels of both types of human capital, b^* and K^*, cannot be determined analytically as it will depend on the probabilities of shock realisations.

What we find from a look at the individual cases is the following. Firstly, with either positively or negatively symmetric shocks, their impact on the equilibrium works through the same channels as the impact of price p. In the case of asymmetric shocks, however, we find that price p and shock A are no longer linked. And while there is a direct effect from the exogenous price level only on intensive human capital b^*, the price shock augments both intensive b^* and extensive human capital K^*. Intuitively, a bigger shock widens the differential in the marginal product of a given worker with the two firms. Therefore, employment is shifted towards the positively affected firm. Additionally, the wage at firm 1 increases while it falls at firm 2. At the same time, training cost for firm 1's (firm 2's) workers rise (fall), but the training cost effect is outweighed by the change in the marginal product. Workers thus shift from a lower wage towards a higher wage net of training cost. With equal probability on the four shock scenarios, simulations suggest the overall effect to be positive.

Result 3:

$$db^*/dL < 0; \;\; dK^*/dL$$

While the overall shock-weighted effect of labour market size L on specific human capital b^* can be shown to be negative, it is not possible to analytically determine the impact on general human capital K^*.

An increase in the size of the market generally reduces the returns to an additional unit of specific human capital b as a larger market puts downward pressure on wages. The impact of market size on general human capital K^*, however, depends upon the direction of shocks.

An increase in L means that, with worker density constant, there are now more workers in the local labour market. We thus interpret L as a measure of labour market size. Training cost are rising in market size but falling in extensive human capital. Therefore, in a larger market, the return on extensive human capital K increases as K can compensate for the rise in training costs resulting from a larger average distance of a worker from her firm. There is also a negative effect from market size on wages, as in a larger market competition for workers is relaxed. We have thus identified two reasons why we should find a higher level of general human capital K^* in bigger markets. These two effects, however, only emerge when firms compete for the marginal worker as observed with positively symmetric, and with asymmetric shocks. Things are different when there is unemployment. Here, both training cost and the paid wage are independent of market size. The reason is that firms now set monopoly wages thus internalising labour supply decisions. Finally, there is an important effect specific to the case of asymmetric shocks: A higher level of general human capital K shifts employment towards the firm offering the higher wage. Thus the expected wage for a worker rises, and so does the return to an additional unit of K.[7] In summary, in a larger labour market, we should observe a lower level of specific human capital b^*. The impact on general human capital K^* is analytically ambiguous as it resembles the outcome of opposing forces generated by the various shock combinations.

[7]This rise in the marginal return becomes the more important, the larger the distance of a worker from her firm.

		Firm 2	
		$p+A$	$p-A$
Firm 1	$p+A$	$\frac{\theta}{2}$	$\frac{1-\theta}{2}$
	$p-A$	$\frac{1-\theta}{2}$	$\frac{\theta}{2}$

Table 2: A specific probability structure

5 Industry- versus Firm-specific Shocks

So far, we have attached probabilities π_1, π_2, and $1-\pi_1-\pi_2$ to the three cases of positively symmetric, negatively symmetric, and asymmetric shocks. We now introduce a more specific probability structure. Shocks are symmetrically distributed with probability θ, $\frac{\theta}{2}$ for positive and negative symmetry each, and asymmetrically with probability $1-\theta$. This will allow us to study the impact of changes in the probability structure on the equilibrium outcome. Table 2 shows the resulting probabilities for the four potential outcomes.

Interpreting θ as a measure of the degree of symmetry of shocks, we are thus able to observe, how the optimal values of human capital investment change when symmetric shocks become more likely.

Studies investigating the effects of demand uncertainty, for example Jellal *et al.* (1999), tend to consider only the extent or volatility of shocks as measured by the variance of continuously distributed shocks. Firms are then assumed to know the parameters of the distribution and subsequently internalise this information. Despite the seemingly elegant modelling of shocks, such studies have ignored the effects arising from the co-movement of shocks at different firms (i.e. the covariance). Instead they have worked with a representative firm based on the fact that expected values and variances of shocks are the same for all firms. Here, we have chosen a different route: we explicitly model firms' adjustment to shocks that are revealed by nature. Each firm's labour market behaviour is thus not only affected by its own shock realisation but also by the shock to the rival

firm.[8] In our context, as θ increases shocks become more symmetric while with a lower θ the likelihood of asymmetric shocks rises.

Result 4:

$$db^*/d\theta < 0; \;\; dK^*/d\theta < 0$$

As shocks become less symmetric the incentive for a worker to invest in both types of human capital increases[9].

The threat of unemployment in case of negatively symmetric shocks and the associated absence of returns to human capital investment outweigh the positive effect on wages, and thus higher returns to human capital investment, when shocks are positively symmetric. Alternatively, there is a very strong influence derived from the labour market pooling argument.

Conversely, in a region with a more diversified industrial structure workers have stronger incentives to accumulate both general and specific human capital. This is because the pooling set-up not only enables firms to insure one another against labour shortages but also workers are insured against unemployment, an argument suggested by MARSHALL (1920) and formally developed in KRUGMAN (1991).

It is particularly the worker in the middle of line L that gains most from additional human capital under asymmetric shocks, and who faces unemployment with negatively symmetric shocks. These workers will switch from the adversely affected firm towards the positively affected firm and thus increase their wages considerably (wages here being a function of both types of human capital). Workers will thus always find a firm to make use of their directly productive human capital, b, while the complementarity between K and b means that a higher level

[8]This framework does not allow for shocks to take continuously varying values as certain constellations would violate some of the restrictions introduced in section 3.

[9]For the derivation see the appendix.

of general human capital, K, will reinforce this effect.

We can also interpret the symmetry of shocks as an indicator of the degree of regional specialisation. Symmetric shocks are then industry-specific and all firms in the local labour market belong to that industry. Asymmetric shocks represent firm-specific shocks with the two firms belonging to different industries.

The results of our model thus yield predictions for regional performance under closer integration. If integration leads to a process of regional specialisation, as has been observed for the US, and is suggested for European Union members, a region's firms will be hit more often by symmetric shocks. Anticipating precisely that, the regional workforce will accumulate less human capital, given the degree of uncertainty. Therefore, the process of regional specialisation may yield a pattern where workers are less trained in the long run. With our modified structure of shock probabilities, we are thus able to link our paper to the discussion on shock incidence as European integration proceeds.

If we now combine the model's implications with the predictions of endogenous growth theory, a cumulative process may be set in motion. Human capital plays a central role in one strand of endogenous growth models: It is via human capital investment that perpetual growth becomes possible. Within such a framework, we suggest that, everything else being constant, an uncertain product market combines with a heterogeneous and pooled labour market in an industrially specialised area to depress the long-run growth rate.[10]

The issue of symmetry of (demand) shocks and regional specialisation is thus of double importance as Europe is becoming more integrated. Firstly, spatial concentration will increase the likelihood of asymmetric shocks between regions at a time when, in the case of countries, the absence of the exchange rate policy instrument makes adjustment difficult. This is the argument familiar from the

[10]Of course, there will be benefits from regional specialisation, as is highlighted in models of new economic geography, for example, which may or may not offset the negative effects of product market uncertainty.

optimal currency area literature, and is often employed in estimates of the cost of European Monetary Union. We argue that, secondly, specialisation and the associated symmetry of shocks within regions may also lead to lower levels of the regional human capital stock with adverse effects on regional growth performance.

In conclusion, the interaction of product market uncertainty with spatial concentration of industry may reduce the incentive for a worker in a pooled labour market to invest in human capital. This could then offset the advantages arising from specialisation and agglomeration such as pecuniary or other externalities.

6 Conclusion

The European effort towards deeper economic and monetary integration has provoked a great deal of literature on the possibly detrimental effects on cross-regional economic performance. The loss of the exchange rate instrument in response to country-specific shocks as well as the observed widening of regional income differentials both have given rise to concern. In addition, models of new economic geography have shown how forces associated with closer integration can initiate circular processes which in turn may lead industries to concentrate in space, regional inequality then being exacerbated. Against this background, we have investigated the labour market outcome and human capital formation in a region that is characterised by product market shocks, worker and firm heterogeneity, and a pooled labour market.

We add to the current discussion by introducing the endogenous formation of differentiated human capital as an important source of workforce flexibility, i.e. a region's capacity to adapt to changes in labour market or product market conditions. Our results are thus the outcome of a quite complex interaction between firms' labour market behaviour and workers' human capital decisions, both being endogenous, and the exogenously given structure of shocks.

Our results have implications not only for the labour market outcome, but

also for long-run growth prospects in a region. In a first step, if closer integration causes regions to become more specialised in their industrial structure, the likelihood of symmetric product market shocks weakens the incentive for workers to invest in human capital. If, at the same time, the degree of skill differentiation rises the incentive to invest in specific human capital is even lower. Instead, workers raise their general human capital in order to reduce adjustment costs. Both mechanisms may lead to a lower human capital stock in the respective region, and ultimately to lower long-run growth.

Our model has produced a number of testable hypotheses. At a more practical level, it advises regional policy makers to devote their attention to human capital formation. We have shown how uncertainty in product markets and its consequences for firm behaviour is anticipated by workers when deciding upon their human capital investment. European policy-makers should therefore take these long-term effects into account when shaping the institutional setting in regions.

A Mathematical Appendix

Total expected Bertrand wage

$$\begin{aligned}\omega_B^e &= (b(p+A) - \frac{5}{4}\frac{L}{K})\pi_1 + \frac{1}{4}(p-A)^2 b^2 \frac{K}{L}\pi_2 \\ &+ (pb + \frac{1}{9L}b^2A^2K - \frac{5}{4}\frac{L}{K})(1-\pi_1-\pi_2) - C(b,K)\end{aligned}$$

A.1 First-order conditions with respect to b and K

$$\begin{aligned}\frac{\partial \omega_B^e}{\partial b} &= \pi_1(p+A) + \pi_2(p-A)^2\frac{bK}{2L} - (1-\pi_1-\pi_2)(p + \frac{2bA^2K}{9L}) - C_b = 0 \\ \frac{\partial \omega_B^e}{\partial K} &= \pi_1\frac{5}{4}\frac{L}{K^2} + \pi_2\frac{b^2}{4L}(p-A)^2 + (1-\pi_1-\pi_2)(\frac{b^2A^2}{9L} + \frac{5}{4}\frac{L}{K^2}) - C_K = 0\end{aligned}$$

A.2 Total Differentiation

Totally differentiating the two first-order conditions yields:

$$\begin{aligned}0 &= \underbrace{(\pi_2(p-A)^2\frac{K}{2L} + (1-\pi_1-\pi_2)\frac{2}{9L}A^2K - C_{bb})}_{\equiv \alpha_{bb}}\, db \\ &+ \underbrace{(\pi_2\frac{b}{2L}(p-A)^2 + (1-\pi_1-\pi_2)\frac{2}{9L}bA^2 - C_{bK})}_{\equiv \alpha_{bK}}\, dK \\ &+ \underbrace{(\pi_1 - \pi_2\frac{K}{L}b(p-A) + (1-\pi_1-\pi_2)\frac{4}{9L}bAK)}_{\equiv \beta_A}\, dA \\ &+ \underbrace{(-\pi_2\frac{K}{2L^2}b(p-A)^2 - (1-\pi_1-\pi_2)(\frac{2}{9L^2}bA^2K))}_{\equiv \beta_L}\, dL \\ &+ \underbrace{(\pi_1 + \pi_2(p-A)b\frac{K}{L} + (1-\pi_1-\pi_2))}_{\equiv \beta_p}\, dp\end{aligned}$$

$$
\begin{aligned}
0 &= \underbrace{(\pi_2 \frac{b}{2L}(p-A)^2 + (1-\pi_1-\pi_2)\frac{2}{9L}bA^2)}_{\equiv \alpha_{Kb}}\, db \\
&+ \underbrace{((1-\pi_2)(-\frac{5}{2}\frac{L}{K^3} - C_{KK})}_{\equiv \alpha_{KK}}\, dK \\
&+ \underbrace{(\pi_1 \frac{5}{4K^2} - \pi_2 \frac{1}{4L^2}(p-A)^2 b^2 + (1-\pi_1-\pi_2)(-\frac{b^2A^2}{9L^2} + \frac{5}{4K^2}))}_{\equiv \kappa_L}\, dL \\
&+ \underbrace{(\pi_2 (p-A)\frac{b^2}{2L})}_{\equiv \kappa_p}\, dp \\
&+ \underbrace{(-(\pi_2 (p-A)\frac{b^2}{2L} + (1-\pi_1-\pi_2)(\frac{2}{9L}b^2A))}_{\equiv \kappa_A}\, dA
\end{aligned}
$$

Combining these two equations we obtain:

$$
\begin{pmatrix} (\pi_2(p-A)^2\frac{K}{2L} + (1-\pi_1-\pi_2)\frac{2}{9L}A^2 - C_{bb}) & (\pi_2\frac{b}{2L}(p-A)^2 + (1-\pi_1-\pi_2)\frac{2}{9L}bA^2) \\ (\pi_2\frac{b}{2L}(p-A)^2 + (1-\pi_1-\pi_2)\frac{2}{9L}bA^2) & ((1-\pi_2)(-\frac{5}{2}\frac{L}{K^3} - C_{KK}) \end{pmatrix} \begin{pmatrix} db \\ dK \end{pmatrix}
$$

$$
\begin{aligned}
= &- \begin{pmatrix} -\pi_2 \frac{K}{2L^2} b(p-A)^2 - (1-\pi_1-\pi_2)(\frac{2}{9L^2}bA^2K) \\ \pi_1 \frac{5}{4}\frac{1}{K^2} - \pi_2 \frac{b^2}{4L^2}(p-A)^2 + (1-\pi_1-\pi_2)(-\frac{b^2A^2}{9L} + \frac{5}{4K^2}) \end{pmatrix} dL \\
&- \begin{pmatrix} \pi_1 - \pi_2 \frac{K}{L} b(p-A) + (1-\pi_1-\pi_2)\frac{4}{9L}bAK \\ -(\pi_2(p-A)\frac{b^2}{2L}) + (1-\pi_1-\pi_2)(\frac{2}{9L}b^2A) \end{pmatrix} dA \\
&- \begin{pmatrix} \pi_1 + \pi_2(p-A)b\frac{K}{L} + (1-\pi_1-\pi_2) \\ \pi_2(p-A)\frac{b^2}{2L} \end{pmatrix} dp
\end{aligned}
$$

In terms of the previously defined abbreviations:

$$
\begin{pmatrix} \alpha_{bb} & \alpha_{bK} \\ \alpha_{bK} & \alpha_{KK} \end{pmatrix} \begin{pmatrix} db \\ dK \end{pmatrix} = - \begin{pmatrix} \beta_L \\ \kappa_L \end{pmatrix} dL - \begin{pmatrix} \beta_A \\ \kappa_A \end{pmatrix} dA - \begin{pmatrix} \beta_p \\ \kappa_p \end{pmatrix} dp
$$

A.3 Restrictions

Restrictions resulting from the second-order conditions for wage maximisation (concavity restrictions):

$$\begin{aligned} c_1 &\equiv (\pi_2(p-A)^2\frac{K}{2L} + (1-\pi_1-\pi_2)\frac{2}{9L}A^2K - C_{bb}) < 0 \\ c_2 &\equiv ((1-\pi_2)(-\frac{5}{2}\frac{L}{K^3} - C_{KK}) < 0 \\ & \quad c_1c_2 - (c_3)^2 > 0 \\ \text{with} \quad c_3 &\equiv \pi_2(p-A)^2\frac{b}{2L} - (1-\pi_1-\pi_2)\frac{2}{9L}bA^2 - C_{bK}) \end{aligned}$$

Other parameter restrictions (see section 3):

$$\begin{aligned} R_1 &\equiv b(p+A) - \frac{3L}{2K} \geq 0 \\ R_2 &\equiv b(p-A) - \frac{L}{K} \leq 0 \\ R_3 &\equiv pb - \frac{3L}{2K} \geq 0 \end{aligned}$$

A.4 Comparative Statics

We can now solve for the comparative static effects. The sign of $\frac{db}{dp}$ and $\frac{dK}{dp}$ is immediately obvious from inspection of the relevant terms in the total differentials, and from the restrictions:

$$\begin{aligned}
\frac{db}{dp} &= \underbrace{\frac{1}{det}}_{+}\left(\underbrace{\alpha_{KK}(-\beta_p)}_{-/-} - \underbrace{\alpha_{bK}(-\kappa_p)}_{+/-}\right) > 0 \\
\frac{dK}{dp} &= \underbrace{\frac{1}{det}}_{+}\left(\underbrace{\alpha_{bb}(-\kappa_p)}_{-/-} - \underbrace{\alpha_{bK}(-\beta_p)}_{+/-}\right) > 0
\end{aligned}$$

The sign of $\frac{db}{dA}$ and $\frac{dK}{dA}$ is undetermined as it depends on the specification of probabilities for the shock realisations.

$$\begin{aligned}
\frac{db}{dA} &= \underbrace{\frac{1}{det}}_{+}\left(\underbrace{\alpha_{KK}(-\beta_A)}_{-/?} - \underbrace{\alpha_{bK}(-\kappa_A)}_{+/?}\right) \\
\frac{dK}{dA} &= \underbrace{\frac{1}{det}}_{+}\left(\underbrace{\alpha_{bb}(-\kappa_A)}_{-/?} - \underbrace{\alpha_{bK}(-\beta_A)}_{+/?}\right)
\end{aligned}$$

The sign of dK/dL is also undetermined:

$$\frac{dK}{dL} = \underbrace{\frac{1}{det}}_{+}\left(\underbrace{\alpha_{bb}(-\kappa_L)}_{-/?} - \underbrace{\alpha_{bK}(-\beta_L)}_{+/+}\right)$$

whereas the sign db/dL can be shown to be negative:

Replacing $(1 - \pi_1 - \pi_2)$ by π_3,

$$
\begin{aligned}
\frac{db}{dL} &= \frac{1}{det}(\alpha_{KK}(-\beta_L) - \alpha_{bK}(-\kappa_L)) \\
&= \frac{1}{det}((-\pi_1\frac{5}{2}\frac{L}{K^3} - \pi_3\frac{L}{K^3} - C_{KK})(\pi_2\frac{K}{2L}(p-A)^2 b + \pi_3\frac{2}{9L^2}bA^2K)) \\
&- (\pi_2\frac{b}{2L}(p-A)^2 + \pi_3\frac{2}{9L}bA^2)(-\pi_1\frac{5}{4K^2} + \pi_2\frac{b^2}{4L^2}(p-A)^2 - \pi_3(\frac{5}{4K^2} - \frac{b^2A^2}{9L^2}))) \\
&= \frac{1}{det}(\alpha_{KK}\beta_L + \pi_3\pi_2\frac{5}{8K^2L}(p-A)^2 b - \pi_3\pi_1\frac{2}{9}\frac{5}{4}\frac{bA^2}{K^2L} - \alpha_{bK}\pi_2\frac{b^2}{4L^2}(p-A)^2 \\
&+ \pi_2\pi_3\frac{5}{8K^2L}(p-A)^2 b + (\pi_3)^2\frac{5}{4}\frac{2}{9}\frac{bA^2}{LK^2} - \alpha_{bK}\pi_3\frac{b^2A^2}{9L^2}) \\
&= \frac{1}{det}(-\pi_1\pi_2\frac{5}{4K^2L}(p-A)^2 b - \pi_2\pi_3\frac{5}{4K^2L}(p-A)^2 b - C_{KK}\beta_L \\
&- \alpha_{bK}(\pi_2\frac{b^2}{4L^2}(p-A)^2 + \pi_3\frac{b^2A^2}{9L^2}) + \pi_2\pi_1\frac{5}{8K^2L}(p-A)^2 b \\
&- \pi_3\pi_1\frac{2}{9}\frac{5}{4}\frac{bA^2}{K^2L} + (\pi_3)^2\frac{5}{4}\frac{2}{9}\frac{bA^2}{K^2L} - \pi_1\pi_3\frac{5}{9}\frac{bA^2}{K^2L} - (\pi_3)^2\frac{5}{9LK^2}bA^2 + \pi_2\pi_3\frac{5}{8K^2L}(p-A)^2 b) \\
&= \underbrace{\frac{1}{det}}_{>0}(\underbrace{-C_{KK}\beta_L - \alpha_{bK}(\pi_2\frac{b^2}{4L^2}(p-A)^2 + \pi_3\frac{b^2A^2}{9L^2})}_{<0}) \\
&- \underbrace{(+\pi_1\pi_2\frac{5}{4K^2L}(p-A)^2 b + \pi_2\pi_1\frac{5}{8K^2L}(p-A)^2 b)}_{>0} \\
&+ \underbrace{(-\pi_2\pi_3\frac{5}{4K^2L}(p-A)^2 b - \pi_2\pi_3\frac{5}{8K^2L}(p-A)^2 b)}_{<0} \\
&+ \underbrace{(-\pi_1\pi_3\frac{5}{9K^2L} + \pi_1\pi_3\frac{2}{9}\frac{5}{4K^2L}bA^2)}_{<0} - \underbrace{(-(\pi_3)^2\frac{5}{4}\frac{2}{9}\frac{bA^2}{K^2L} + (\pi_3)^2\frac{5}{9}\frac{bA^2}{K^2L})}_{>0}
\end{aligned}
$$

Consequently:

$$
\frac{db}{dL} = \underbrace{\frac{1}{det}}_{+}(\underbrace{\alpha_{KK}(-\beta_L)}_{-/+} - \underbrace{\alpha_{bK}(-\kappa_L)}_{+/?}) < 0
$$

A.5 Comparative Statics for varying shock probabilities

Shock probabilities π_1 and π_2 are both replaced by $\frac{\theta}{2}$, so that θ reflects the likelihood of symmetric shocks, and $(1-\theta)$ that of asymmetric shocks.
The total expected Bertrand wage with θ is then:

$$\begin{aligned}\omega^e_{B_\theta} &= (b(p+A) - \frac{5}{4}\frac{L}{K})\frac{\theta}{2} + \frac{b^2}{4}(p-A)^2\frac{K}{L}\frac{\theta}{2} \\ &+ (pb + \frac{K}{9L}b^2A^2 - \frac{5}{4}\frac{L}{K})(1-\theta) - C(b,K)\end{aligned}$$

The first-order conditions are analogous to the ones before, while the total differential now takes into account the existence of the additional exogenous parameter θ:

$$\begin{pmatrix} \alpha_{bb} & \alpha_{bK} \\ \alpha_{bK} & \alpha_{KK} \end{pmatrix} \begin{pmatrix} db \\ dK \end{pmatrix} = - \begin{pmatrix} \beta_L \\ \kappa_L \end{pmatrix} dL - \begin{pmatrix} \beta_A \\ \kappa_A \end{pmatrix} dA - \begin{pmatrix} \beta_p \\ \kappa_p \end{pmatrix} dp - \begin{pmatrix} \beta_\theta \\ \kappa_\theta \end{pmatrix} d\theta$$

with

$$\begin{aligned}\beta_\theta &= p + A + \frac{K}{2L}b(p-A)^2 - 2p - \frac{4}{9L}bKA^2 \\ \kappa_\theta &= \frac{5}{4}\frac{L}{K^2} + \frac{b^2}{4L}(p-A)^2 - 2\frac{5}{4}\frac{L}{K^2} - \frac{2}{9L}b^2A^2\end{aligned}$$

Both β_θ and κ_θ can be shown to be negative:

Sign of κ_θ:

$$\begin{aligned}
\kappa_\theta &= \frac{5}{4}\frac{L}{K^2} + \frac{b^2}{4L}(p-A)^2 - 2\frac{5}{4}\frac{L}{K^2} - \frac{2}{9L}b^2A^2 \\
&= \frac{5}{4}\frac{L}{K^2} - \frac{2}{9}\frac{b^2A^2}{L} + \frac{b^2}{4L}(p-A)^2 - \frac{5}{2}\frac{L}{K^2} \\
&= \underbrace{((p-A)b)}_{\equiv x}((p-A)b) - \underbrace{(\frac{L}{K})}_{\equiv y}(5\frac{L}{K})\underbrace{-\frac{8}{9}b^2A^2}_{<0}
\end{aligned}$$

by restriction R2:

$$\begin{aligned}
x &< y \\
\Rightarrow \quad x(x) &< y(5y) \\
\Rightarrow \quad \kappa_\theta &< 0
\end{aligned}$$

Sign of β_θ:

$$\begin{aligned}
\beta_\theta &= p + A + \frac{K}{2L}b(p-A)^2 - 2p - \frac{4}{9L}bKA^2 \\
&= \frac{bK}{2L}\,(p-A)^2 + (A-p) - \frac{4}{9L}A^2bK \\
&= \frac{bK}{L}\,(\frac{1}{2}(p-A)^2 - \frac{4}{9}\frac{A^2}{L}) + (A-p) \\
&= \frac{bK}{18L}\,(9(p-A)^2 - 8A^2) + (A-p) \\
&= \frac{bK}{18L}\,(8(p-A)^2 - 8A^2) + \frac{bK}{18L}(p-A)^2 - (p-A) \\
&= \frac{bK}{18L}\,(8p^2 - 16pA + 8A^2 - 8A^2) + (p-A)(\frac{bK}{18L}(p-A) - 1) \\
&= \frac{bK}{18L}\,(8p^2 - 16pA) + \frac{(p-A)}{18L}\quad \underbrace{(bK(p-A) - L}_{<0 \text{ by Restriction R2}} \quad -17L)
\end{aligned}$$

$$\begin{aligned}
&\frac{1}{18L}\,(bK8p(p-2A) - 17L(p-A)) \\
&= \frac{1}{18L}\,(bK8(p^2 - 2Ap + A^2) - 17L(p-A) - bK8A^2) \\
&= \frac{1}{18L}\,(bK8(p-A)^2 - 8L(p-A)\underbrace{-9(p-A)L - bK8A^2)}_{<0}
\end{aligned}$$

$$\frac{1}{18L}\,(8(p-A)(\quad \underbrace{(p-A)bK-L}_{<0 \text{ by Restriction R2}}\quad))$$

$$\Rightarrow\ \beta_\theta < 0$$

The overall comparative static effects with respect to θ are therefore negative:

$$\begin{aligned}
\frac{db}{d\theta} &= \frac{1}{det}\,\underbrace{(\alpha_{KK}(-\beta_\theta)}_{-/+} - \underbrace{\alpha_{bK}(-\kappa_\theta)}_{+/+}) < 0 \\
\frac{dK}{d\theta} &= \frac{1}{det}\,\underbrace{(\alpha_{bb}(-\kappa_\theta)}_{-/+} - \underbrace{\alpha_{bK}(-\beta_{\theta)})}_{+/+} < 0
\end{aligned}$$

A.6 Probability distribution of prices

The distribution of prices underlying our specification of the probability structure in Table 1 is characterised as follows:

Marginal Distribution:

$$p_i = \begin{cases} p+A & \text{with probability } \dfrac{1+\pi_1-\pi_2}{2} \\ p-A & \text{with probability } \dfrac{1-\pi_1+\pi_2}{2} \end{cases}$$

with p_i the output price for firm i, $i \in \{1,2\}$

Expected Value:

$$E(p_i) = p + A(\pi_1 - \pi_2)$$

Variance:

$$\begin{aligned} Var(p_i) &= \frac{1+\pi_1-\pi_2}{2}(p+A-E(p_i))^2 + \frac{1-\pi_1+\pi_2}{2}(p-A-E(p_i))^2 \\ &= A^2(1-(\pi_1-\pi_2)^2) \end{aligned}$$

Covariance (using Table 1):

$$\begin{aligned} Cov(p_1,p_2) &= \pi_1(p+A-E(p_1))(p+A-E(p_2)) + \pi_2(p-A-E(p_1))(p-A-E(p_2)) \\ &\quad + \frac{1-\pi_1-\pi_2}{2}(p+A-E(p_1))(p-A-E(p_2)) \\ &\quad + \frac{1-\pi_1-\pi_2}{2}(p-A-E(p_1))(p+A-E(p_2)) \\ &= A^2(2(\pi_1+\pi_2)-1-(\pi_1-\pi_2)^2) \end{aligned}$$

Correlation Coefficient:

$$\begin{aligned} \rho(p_1,p_2) &= \frac{Cov(p_1,p_2)}{\sqrt{Var(p_1)}\sqrt{Var(p_2)}} = \frac{Cov(p_1,p_2)}{Var(p_i)} \\ &= \frac{2(\pi_1+\pi_2)-1-(\pi_1-\pi_2)^2}{1-(\pi_1-\pi_2)^2} \end{aligned}$$

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